Recommendations for a Department of Energy Nuclear Energy R&D Agenda

Appendix 4
Options for Policy and Research & Development

EXECUTIVE SUMMARY

Safety, security (safeguards, security, and proliferation concerns), environment and waste management (including disposal), cost, and public acceptance are the prime factors affecting the U.S. nuclear energy program. Although these factors have been of concern since the beginning of the peaceful use of the atom, their relative importance has evolved in the decades since the beginning of nuclear power generation. In the 1960s and early 1970s, public perception of nuclear energy was very positive, and public support was generally taken for granted. Permanent waste management was an issue too far in the future to be worried about. Proliferation was just a topic for experts. Electricity was said to be too cheap to meter. The only subject that warranted immediate concern was safety. Today, cost, the environment, and waste management issues have emerged to dominate the domestic nuclear energy scene, and proliferation is the major international issue for the U.S.

Thus, the first generation of nuclear power in the U.S. started in a way that was not based on today's realities or on likely long-term realities. It may be very difficult to restart the U.S. nuclear power program without an overhaul of the entire system. A partial correction will not likely be sufficient.

With this situation in mind, it is appropriate to consider the conditions and scenarios that may unfold as the future of the U.S. nuclear energy program develops. In this paper, three Scenarios or phases that represent possible components of the future development of nuclear power are identified and discussed. The three Scenarios, which are not mutually exclusive but rather can be viewed as sequential phases taken in combination, include: Scenario 1, representing the current situation in the U.S. in which there are no new orders for nuclear power plants; Scenario 2, in which actions are taken to maintain the current (20%) level of the nuclear option; and Scenario 3, in which fission power grows in a less constrained manner as a preferred source of new generation capacity. The identification and discussion of these Scenarios leads directly to consideration of the policy implications and research needs that will be necessary to effectively support the continued viability of the nuclear power option in the U.S.

Scenario 1. Gradual abandonment of the U.S. nuclear option. Although in the current situation, there are no new nuclear power plant orders in the U.S., we cannot stop the world community from pursuing the nuclear power option. As a basic concern, nuclear proliferation is tied to the international issues over which

the U.S. has even less control. We must initiate a U.S. nuclear energy program to secure technology leadership and thereby be more effective in influencing the world community on nuclear matters, including the advancement of our policies on proliferation. Under this Scenario, there are a few activities (including R&D) that we should pursue to achieve our goals:

- Develop a small nuclear reactor system based on integration of the entire fuel cycle, i.e., safety, proliferation, waste management, and cost. The primary driver is proliferation concerns.

- Take effective steps to extend the safe, economic operating life of existing plants to ensure a robust energy supply and minimize increased greenhouse gas emissions.

- Maintain critical underlying educational and research infrastructures through focused research initiatives between the universities and national laboratories.

- Increase international technical dialogue, particularly with the developing nations of East Asia in order to secure and maintain vital U.S. interests.

Scenario 2. Continued reliance on nuclear generation. If fission power is to continue to be depended upon for the generation of roughly 20% of our electricity, we must overhaul the nuclear power system. A partial fix will not do. Only a new system of nuclear power generation that balances safety, proliferation, waste management, technology, and cost will succeed. Many activities (including R&D) are necessary in addition to those of Scenario 1 development:

- Develop initiatives to reduce cost with improved safety.
  - Safety regulations and standards reform.
  - Quality assurance reform.
  - Regulatory philosophy reform.

- Improve public understanding and perception of nuclear energy.

- Integrate nuclear fuel cycle elements into nuclear reactor system development.

Scenario 3. Reemergence of nuclear power as a preferred choice for future base-load electricity generation. If fission reactors are going to play a major role in base-load electricity generation in the U.S., we must develop new technologies and approaches to take full advantage of the developments included in Scenarios 1 and 2. The activities above and beyond Scenarios 1 and 2 include:

- Advanced reactor system development.

- Completion of deployment preparation for selected new technologies.

These three Scenarios comprise the spectrum of future possibilities with regard to the nuclear power option. It is essential to anticipate the R&D needs to support these Scenarios not only to effectively plan for the future but also to maintain a meaningful involvement in the development of the international nuclear power industry. Such involvement is key to the need for the U.S. to remain informed and to be positioned to influence the development of nuclear power on a worldwide basis.

1.0 INTRODUCTION

The future of nuclear energy, both domestically and internationally, is dominated by major uncertainties. Domestically, nuclear energy appears to be in a declining trend, substantially due to energy demand and market uncertainties, increasing pressure caused by growing deregulation of domestic electricity production, and uncertain public acceptance. All domestic energy-demand projections show growth; some suggest slow growth in total energy requirements, but most indicate significant domestic energy growth. Moreover, uncertainties in how best to address future energy needs and to reduce carbon and greenhouse gas emissions and in the future availability and economic viability of alternatives suggest that nuclear power may be needed in the near future.

Internationally, while similar uncertainties are at work in Western Europe, it is clear that developing countries and East Asia will require increasing amounts of energy, and electricity in particular, over the next 50 years, and nuclear power is emerging as one of their preferred options.

Within this environment of certain energy demand growth, coupled with significant uncertainty with respect to all energy sources, it is vital to maintain and develop all viable options toward ensuring a stable energy supply for the future. At issue here is not a comparative assessment of the prospects of nuclear power relative to the alternatives, rather it is an analysis of the risks and benefits of nuclear power, of the research efforts needed to minimize the risks and realize the benefits, and of the policies and environment within which nuclear power can achieve renewed interest.

This analysis begins with a brief review of the perspectives and issues underlying the nuclear power option. We then define a series of scenarios, or alternative futures, for the role of nuclear power in the nation's and world's energy market as a tool for visualizing implications, risks, and benefits of nuclear power. From this basis, we then develop the requirements for R&D and policy support needed to address the implications, minimize the risks, and realize the benefits of nuclear power in the future.

2.0 PERSPECTIVES

The future of nuclear power generation in this country and abroad is at a critical point. Although a competitive alternative, nuclear power has insufficient political and public acceptability in many countries, including the U.S., to support the substantial economic and social costs of increased reliance on its use. Increasing emphasis on short-term energy economics is undermining the long-term economic advantages of nuclear power. The broad energy picture (i.e., supply and demand, domestic and international) is in a state of conditional stability (i.e., at saddle-point). Energy prices and supplies are reasonably stable, and demand growth is generally under control. However, population pressures and the industrialization of developing countries are leading to significant new energy demands in the coming decades. These pressures, along with the increasing environmental, economic, and geopolitical concerns related to burning fossil fuels, will contribute to increased demand for new nuclear power technologies and greater generating capacity.

Safety, security (safeguards, security, and proliferation concerns), waste management (including disposal), cost, and public acceptance are the prime factors affecting the U.S. nuclear energy program. Those factors have been of concern since the beginning of the peaceful use of the atom. For the last 40 years, the relative importance of these factors has changed to reflect social, economic, and political changes. To identify what policies and research will be necessary to support a U.S. nuclear energy program, we must define the objectives of such a program and, in addition, we must identify the major concerns of the U.S. government, the utility industry, and the general public that might affect this program.

While there continue to be large uncertainties and differences of opinion about the future role of nuclear energy both in the United States and abroad, it has national security, economic, and environmental dimensions that are of primary concern. The future of nuclear energy hinges on a number of key principles, objectives, and assumptions:

- Nuclear power supplies more than 20% of the nation's electricity, and currently operating reactors will continue to supply a significant amount for decades.
- Meeting U.S. electrical energy demands is key to continued economic growth and security. A diverse set of production alternatives, including nuclear, is vital to the national interest in the mid-to-long term.
- Programs to assure that safety, environmental, and waste management problems are solved with favorable economics are essential to a viable nuclear option; regardless of the future of nuclear power, the benefits from nuclear activities over the past 50 years have left a legacy of materials, wastes, and facilities that will require long-term nuclear expertise.
- Environmental, national security, and economic developments and surprises can have short-term, substantial impacts on the relative advantages of respective energy sources. In particular, the environmental advantages of nuclear reactors, which do not create emissions related to greenhouse gases or acid rain, provide an essential energy resource to address environmental security issues and needs.
- Energy demands in the rest of the world are expected to grow dramatically, and the growth of nuclear power may be much greater in developing countries. Even in the slowest-growth projections, total worldwide nuclear generating capacity is expected to grow over the next 50 years. As has been the case for the first 50 years of the Nuclear Age, it is in our national security and economic interest to maintain international leadership and expertise in nuclear energy, assuring that we have maximum impact on the proliferation, safety, environmental, material control, and waste management aspects of nuclear developments worldwide.
- A vibrant U.S. educational infrastructure and the maintenance of critical skills, technology, and facilities are essential to our ability to meet future national challenges but the existing infrastructure may erode to unacceptable levels without a healthy national nuclear research agenda.

2.1 Time-frame

Many of the issues surrounding nuclear power are long-lived. The average plant lifetime is on the order of 30 years. Nuclear waste has a very long life. Because of these long time-lines, there is a tendency to focus on the longer-term, and to treat nuclear power primarily as an option for the future.

However, if one looks at the current situation, there are a number of features that will become increasingly important earlier on:

- Aging of the current nuclear power fleet, with early retirement of some units, will soon exacerbate the energy supply / demand balance.
- Increased environmental, CO_2, and global warming concerns are increasing the demand for fossil fuel-free energy sources.
- The desire and / or need for nuclear power is increasing among the developing countries, particularly in Asia.
- Civil stocks of plutonium, particularly as separated material but also in spent fuel, are increasing, and with a continued imbalance in mixed oxide (MOX) utilization likely.
- Uranium is inexpensive, a situation exacerbated by excess weapons material supplies.
- There is a near-general consensus that breeders are unnecessary in the next few decades.
- There is a critical decline in nuclear-engineering university programs and enrollment.
- The domestic industrial base for nuclear power is eroding rapidly in the U.S, and even optimistic demands for new nuclear capacity may be insufficient to maintain vital capabilities.

All of these issues presently affect the status of nuclear energy, and pressures from them will increase in the near future. Current trends do not promise solutions within the next two decades.

As an observation, it is interesting to note that the market share for a new generating technology (wood, coal, oil, natural gas, etc.) historically grows at rate of 5% per year. From its beginnings in the 1950s to the late 1960s, U.S. domestic nuclear power shared that same growth rate, but during the 1970s and 1980s, the growth rate of nuclear power greatly exceeded the historic trend. The current installed market share for U.S. nuclear power is, in effect, 20 years ahead of the trend.

2.2 The role of DOE and USGOV in the development of nuclear power

The role of the DOE (and its predecessors) has changed dramatically from that of the early days of the Atomic Energy Commission (AEC). Although now a substantially mature industry, the nuclear industry does not have the resources to meet all the demands that society places on it. There are significant technical challenges having importance to society as a whole, and DOE has responsibilities for meeting many of these challenges. Some of the general issues related to nuclear power that will impact DOE nuclear policy or that can be impacted by DOE nuclear R&D include:

- Energy security.
- Environmental concerns.
- Proliferation concerns.
- Public and workers' health and safety.
- Waste generation and management.
- International trade (jobs for U.S. workers), technology diffusion and cooperation.

2.3 The Future of Nuclear Energy

Current energy trends, if continued, suggest that the U.S. is heading toward a *gradual abandonment* of the nuclear power option. However, growing concern over emissions of carbon dioxide and other greenhouse gases is creating pressure for a *continued reliance* on nuclear power in the U.S., and the *reemergence* of nuclear power as the preferred option for new generating capacity could be possible in the future. These alternative futures, or scenarios, are not entirely mutually exclusive. As the various societal issues and forces change with time, the constraints and incentives affecting the nuclear power option may change, resulting in one scenario's phasing into another over time.

The alternative U.S. nuclear energy futures, and the implications of those futures, are closely tied to the alternative futures for nuclear power internationally. Internationally, nuclear power generation is likely to experience either *growth* or *decline*. It is, of course, possible that globally, nuclear power may maintain its current share of electrical generation. However, the implications of the international nuclear market on U.S. policy and R&D options are sufficiently constrained by these two limiting cases. Thus, we will consider the implications of U.S. options in the face of these two international frameworks.

3.0 KEY ISSUES FOR NUCLEAR ENERGY

The four most visible issues associated with nuclear power (economics, proliferation, safety, and waste management) are only a subset of broader issues of national importance. Vital national issues affecting or affected by nuclear energy R&D can be lumped into three broad categories:

- National security (e.g., nuclear nonproliferation).
- Environment, safety, and health (including nuclear waste management).
- Economic competitiveness (e.g., maintaining the nuclear infrastructure).

Each of these areas encompasses a variety of issues and concerns, although the perspectives from which these issues are viewed vary widely. It is also clear that the various perspectives will change with time, and there are other considerations that affect nuclear energy policy, such as public perception and international obligations.

Each of these issues has implications on both policy and technology, and can be addressed, at least in part, through R&D and technical innovation. DOE policies and R&D objectives must have one common characteristic: They must contribute to, or further, a set of "enduring objectives" for the overall U.S. nuclear policy. These objectives are embodied in the following broad issues.

3.1 National Security

National security encompasses three principal issues: (1) nuclear nonproliferation, (2) energy security, and (3) national defense.

Nuclear nonproliferation is defined here to address proliferation, as well as illicit procurement and use of nuclear materials from the commercial nuclear fuel cycle. Continued development of nuclear power abroad is likely, particularly among the developing nations and throughout Eastern Asia. Such a spread of nuclear power, particularly among less affluent and less stable nations, will increase the need for a strong nonproliferation regime. Development of technologies to improve the proliferation resistance of nuclear power systems can help augment the more traditional safeguards, transparency, and physical security approaches to nonproliferation. Without U.S. leadership in technology development for enhanced security and proliferation resistance, developing countries must choose from the currently available reactor systems, and some may choose reactors having even less desirable proliferation implications.

Energy security, including global sustainability, is here considered an element of national security because of its increasing global importance. The public expects reliable energy supplies at reasonable prices, and our domestic economy and international economic competitiveness demand both. The trend toward energy-market deregulation is reducing the energy sector's resilience and increasing dependence on fossil fuels at a rapid rate, potentially at the expense of long-term sustainability. Development of energy systems less vulnerable to economic and supply disruptions can help reduce one source of international tension and enhance U.S. national security. Nuclear power has and will continue to have an important role in minimizing the U.S. dependence on fossil energy resources and in assuring diversity in the nation's energy supply.

National defense relies heavily on nuclear technology for a variety of needs, from supplying the weapons arsenal to powering naval vessels and spacecraft. The coupling between civilian nuclear R&D and military applications cannot be completely severed, and indeed civilian R&D can contribute effectively to reducing the nation's weapons' legacy, as evidenced in the potential use of civilian power reactors to burn excess weapons plutonium.

Nuclear Nonproliferation

Nuclear proliferation is perceived to be one of the major risks associated with nuclear power. Reducing the risk of proliferation (and / or other diversion of nuclear materials and technologies) is and will remain an important element of U.S. nuclear policy. It is essentially a fact that new nuclear generating capacity will be introduced throughout the world, notably in Asia, and that this new capacity will result in ever-increasing accumulations and shipments of spent fuel. Both Japan and China have commercial reprocessing facilities under construction or planned. Other countries are likely to pursue reprocessing, both as a mechanism for extending energy resources and as a mechanism for waste management. Research into new fuel cycles for reduced spent fuel accumulation and reduced plutonium buildup, as well as research into new processes for proliferation-resistant waste isolation, could have substantial favorable impact on the proliferation resistance of this new generating capacity.

Current national thinking on proliferation appears dominated by a distrust of safeguards in their current form. This leads directly to the U.S. position of (at best) inconsistent "begrudging acceptance" of reprocessing in a few "chosen" countries. It is possible that improved safeguards technologies, increased transparency, and more enthusiastic global acceptance of the international safeguards regime could result in an improved U.S. trust of international safeguards. This could result in increased acceptability of reprocessing.

Energy Security

Nuclear power's ability to ensure a safe, reliable supply of environmentally clean energy is its greatest benefit. The public expects reliable energy supplies at reasonable prices, and our domestic economy and international economic competitiveness demands both. Even in the current energy glut, pressures are building that will result in increased energy prices and increased competition for energy supplies. Pressures to decrease reliance on fossil fuels continue to build. Accumulation of greenhouse gases and other environmental issues are impacting the desirability of coal and natural gas as energy resources. Eventual supply shortages of oil will ultimately shift transportation toward alternative fuels including electricity and natural gas (possibly displacing natural gas for electrical generation), further increasing our dependency on electricity.

Nuclear power has and will continue to have an important role in minimizing the U.S. dependence on fossil energy resources. Even with the current worldwide energy glut, options must be preserved in order to meet future challenges. The current glut cannot be long-lived. Fossil reserves will eventually become more scarce, and political uncertainties and unrest always have the potential for severely changing the current energy picture. Even the U.S., with ample coal reserves for domestic requirements, may ultimately yield to international pressure for a reduction in emission of greenhouse gases and may have to reduce coal's share of electrical power generating capacity in the U.S.

Over the past decade, there has been a trend towards a more market-driven energy economy. This trend is accelerating with increasing deregulation, resulting in new market pressures emphasizing current economics as the primary figure of merit in energy decision-making. This trend is having several major impacts on the diversity and endurance of energy supplies and infrastructures. Utilities are beginning to shed those plants whose operational and capital costs are considered currently uneconomic or even marginally economic. Capital-intensive, new, long-life generating capacity is being ignored in favor of inexpensive, but short-lived, smaller unit generators. These trends are reducing the energy sector's resilience and increasing dependence on fossil fuels at a rapid rate.

There is a strong imbalance between the world's distribution of energy resources (particularly of fossil fuels) and the consumption of these fuels. This imbalance contributes to international tensions and has a destabilizing influence on international politics. As the world's population and overall energy consumption increases, the need for truly sustainable energy resources will become an increasingly important aspect of world stability, and nuclear power is in an ideal position to make a significant contribution. Even with current trends toward a once-through fuel cycle, nuclear power can contribute significant capacity. With advanced fuel cycles, nuclear power can have significant impacts on energy supply sustainability worldwide for very long times.

Conventional knowledge holds that the U.S., while dependent of foreign resources for much of its oil supplies, is self-reliant on its electrical generating capacity. This is, in fact, no longer true, particularly in the Northeast. Recent announcements by Ontario Hydro concerning the possible shutdown of seven of their CANDU reactors can have a significant impact on electricity supplies in the Northeast and illustrate the increasing dependence of U.S. energy supplies on foreign sources.

National Security

The Department has responsibilities for defense materials and technologies, and these responsibilities have been largely segregated from those related to civilian applications of nuclear energy. There are, however, developments ensuing that may blur the distinction between civil and military nuclear programs. Proposals for tritium generation using either an LWR or FFTF, and the use of excess-Pu-derived MOX in commercial reactors are the two prime examples of such blurring.

Major elements of our national defense rely on nuclear power supplies, from naval propulsion reactors for ships and submarines, to radioisotope generators for spacecraft power. Loss of domestic nuclear infrastructures threatens these important capabilities.

3.2 Environment, Safety & Health

The environment, safety, and health area includes the nuclear energy issues of major importance to the general public today. Nuclear energy continues to be the only sufficiently mature technology having *environmental benefits* for the reduction of acid rain, greenhouse gases, and global warming in the near future. Continuing public concerns about the potential health impacts of radiation lead to demands for further improvements in *nuclear safety*, both technically and culturally. Visible progress in *waste management*, particularly in spent fuel disposal, is necessary to reinstill public and industrial confidence in federal energy management.

Environmental Benefits

The environmental benefits of nuclear power as a tool in the fight against increasing greenhouse gas emissions are clear, and nuclear power continues to have great promise for reducing society's adverse impact on the environment. Nuclear power plants are currently displacing some 140 million tonnes of carbon (MtC) emissions per year in the U.S., and nearly 500 MtC annually worldwide. Also, nuclear power plants do not emit volatile organic compounds, nitrogen oxides, carbon monoxide, particulate matter, and sulfur dioxide, all of which come from fossil fuel combustion and have significant health impacts on the public. The Clean Air Act Amendments of 1990 mandated sharp reductions in nitrogen oxide and sulfur dioxide emissions and placed annual limits on these emissions. It will be difficult or impossible to meet these limits without a significant nuclear component to the electrical generation mix. It will also be difficult to meet our international commitments on greenhouse gas emission reductions without a significant nuclear component to the U.S. electric power generation mix.

On the other hand, even though nuclear waste issues appear technically solvable, the apparent inability to resolve nuclear waste political issues will continue to slow public acceptance of nuclear power.

Nuclear Safety

Nuclear safety is perceived as one of the most important issues affecting nuclear power today. Although western reactors are actually quite safe, the graphic events at Three Mile Island and Chernobyl have perhaps irreversibly altered public perception of the risks associated with nuclear power, and have made safety an enduring nuclear issue. The consequences of another nuclear accident such as Chernobyl could lead to demands for termination of the world’s nuclear generators and potentially eliminate the nuclear option for decades to come.

Waste Management

Waste management, particularly that of spent fuel, is one of the dominant concerns the U.S. public has regarding continued use of nuclear energy. The Federal government is having difficulty meeting its statutory responsibility to manage the spent fuel from the nation’s commercial nuclear power plants. Utilities, electricity customers, and state leaders are increasingly frustrated by the Federal inaction on the spent fuel disposal program. The task of nuclear waste disposal has been made much more difficult by nonattainable standards for proving the safety of the repository and by the “set it and forget it” philosophy of repository design. Concrete progress in the management and disposition of all forms of nuclear waste is an essential element for the future of nuclear energy in the U.S. and ultimately in the global community. One subject particularly important to waste management, but common to all nuclear ES&H issues, is the definition of acceptable lower limits of radiation content and exposure, i.e., definition of an acceptable minimus.

3.3 Economic Competitiveness

Economic competitiveness is an increasingly important issue in an increasingly global economy. International power and influence is ever more closely coupled with economic strength and competitive advantage in the marketplace. Both our domestic standard of living and our ability to compete internationally are dependent on favorable energy *economics*. The U.S. ability to impact foreign nuclear policy will depend substantially on U.S. involvement in the nuclear markets, and the economic competitiveness of the domestic U.S. nuclear energy *infrastructure* is synergistically linked to our foreign competitiveness and influence.

Economics

The economics of nuclear power in a changing domestic energy market is an increasingly important issue. The ability of nuclear power to compete domestically with other alternatives is dependent on several important issues. One is nuclear energy’s ability to compete fairly with other forms of generation, an issue increasingly uncertain under pending deregulation. The other issue is nuclear’s ability to fulfill cost and schedule promises. Whether the economics are a cost or benefit of nuclear power will depend as much on the economics of the alternatives as on the economics of nuclear power.

Deregulation may represent the greatest threat to the economics of many nuclear power plants. Under deregulation, the cost bases for assessing and recovering capital are changing in a way that penalizes capital-intensive installations. Nuclear plants (and similarly, large coal-fired baseload plants) were constructed at a time when recovery of capital costs over the normal operating life of the plant was essentially assured. Even though operating costs at many plants are low enough that they generate power at very competitive prices, plants with large undepreciated capital costs will be at a distinct disadvantage in a deregulated environment even in light of lower operating costs. Without some mechanism for equitably dealing with these “stranded costs,” deregulation is likely to lead to a situation where, on paper, it is more profitable to close major power plants even though their operating costs may be less than the competition.

Whether in the current market or in a deregulated market, new domestic nuclear power plants will only be built if it can be shown that they can be constructed and operated cost effectively and on schedule. Industry is working hard to meet this challenge by increasing reliability, improving operations and extending fuel lifetime. New technologies, materials, and processes are needed to make even more progress. Improvements in the regulatory process have helped reduce both cost and schedule uncertainties, but even more is needed to effect real improvements in cost and schedule while simultaneously improving safety in real terms.

Infrastructure

Infrastructure is the basis of the U.S. nuclear capability, and it is in serious jeopardy. Overall economic competitiveness of U.S. nuclear energy depends on the maintenance of this capability and underlying infrastructure. Even in a future with dwindling domestic nuclear power, much of the existing infrastructure will be needed to ensure safe operation of remaining facilities, and to deal with the long-term waste management issues resulting both from nuclear power and defense activities.

Nuclear engineering enrollment is declining nationally, nuclear engineering departments are being dissolved or absorbed into other departments, and faculties are dwindling. Serious efforts to address this decline are necessary.

Major industries, such as medical and energy industries, increasingly rely on a wide variety of nuclear materials, technologies, and products. DOE (as the AEC) was once responsible for essentially all nuclear material supply, from nuclear fuel to medical and industrial isotopes. Most of these responsibilities have long migrated to the private sector. However, changes in the marketplace, coupled with aging facilities and reluctance to invest in new nuclear facilities, has eroded the country’s abilities to supply important materials, especially medical and industrial isotopes.

3.4 Other Considerations

Other considerations impacting nuclear energy include in general the nation’s need to adhere to international agreements, and the public acceptance of nuclear energy.

International obligations and international relations impact the nation’s responsibilities for nuclear energy and nuclear research and development. As one example, disarmament and resulting fissile materials disposition relies on technologies and infrastructures existing and in development to accomplish goals set by international accords. The U.S. is at odds with many others over the nuclear fuel cycle, citing proliferation and economic issues as overriding, while others place higher value on energy security and believe that the U.S. position contributes to growing plutonium inventories and that plutonium recycling is an effective path to nonproliferation by limiting stockpiles of plutonium. What are the conditions under which these views might change? Under what conditions might the U.S. find itself needing to reopen fuel cycle R&D? What are the likely or potential time-frames, and what do we need to preserve for that eventuality?

Public perception of nuclear energy relies on satisfactory progress in issues already discussed, and on active and overt steps taken to communicate with and involve the public on important nuclear matters. Even more important in today's society, the public must see the DOE and the nuclear industry as being truly responsive to their needs and concerns. An example of this is the public demand for "passively safe" reactors, based on a growing sentiment against reliance on technologies for ultimate safety. The ALWR program addresses this and many of the underlying concerns, but does this program go far enough? Even if nuclear power were to emerge clearly as the technology of choice for future energy needs, implementation of future nuclear technologies will not be possible without public acceptance of nuclear power. Some of the questions underlying this issue include: What is the current level of public confidence in nuclear power, and in DOE? What can DOE do to respond effectively to public concerns and criticisms? What can DOE do to improve public confidence, and what can R&D do to help? Are DOE policies and programs viewed by the public as being reasonable and well thought-out?

Regulatory environment. The current regulatory environment, even with recent advances, will require additional reform for nuclear power to continue to play a major role in the U.S. energy future. Regulatory uncertainties and delays must be further reduced. Regulations must be sufficiently flexible to adapt to new safety technologies without major disruptions to existing systems and infrastructures. Many current regulations are unnecessary, and others inadvertently serve to reduce real safety. These need to be thoroughly reviewed and modified or dropped as appropriate.

Government role. The role of the U.S. government, and of DOE / NE in particular, in the continued development of nuclear energy and the balance between federal and industry funding of nuclear energy R&D are under serious debate. Perhaps even more basic is the question of what *should* the role of nuclear power be over the next 20 to 50 years, and how can DOE help realize that role? Can nuclear power reemerge as part of a bold energy plan in the next decade(s), or is nuclear to be relegated to an "insurance" role? In either case, what are the policy and R&D requirements?

The issues discussed above each have an effect on public attitudes toward nuclear power, Federal policy, and / or private industry investment decisions. Some tend to drive the country towards gradual abandonment of the nuclear option, others tend to support the maintenance of the current level of nuclear activity or even the reemergence of nuclear power as a preferred option. For example, the Federal inaction on the nuclear waste issue tends to discourage the U.S. utilities from wanting to build more nuclear power plants. The lack of effective public information on nuclear safety also tends to encourage the public to prefer a gradual abandonment of the nuclear option. On the other hand, the environmental impacts of the fossil fuel-fired electric power plants are leading some of the public to reconsider the need for nuclear energy. The relationships between the issues (drivers) and scenarios (alternative futures) are summarized in Table 1 below.

Table 1. Relationships between issues and scenarios.

	Gradual abandonment	Continued reliance	Reemergence
Nuclear nonproliferation	X[1]		
Energy security		X	X
National security		X	
Nuclear safety	X		
Environmental impact			X
Waste management	X		
Economics	X[2]		X[2]
Infrastructure		X	

X indicates that the issue is currently tending to bring about that option.

[1] A segment of the public is in favor of gradual abandonment because of proliferation concerns. Gradual abandonment may make the proliferation problem worse.

[2] The current cost of nuclear power is tending toward abandonment of nuclear energy. However, long-term economic competitiveness in light of expected fossil-fuel cost increases may tend toward future reemergence.

In the face of these drivers, three possible scenarios can be envisioned for the future of nuclear power in the U.S. Nuclear power will continue to be a viable option in most of the rest of the world, driven by increasing demand in the developing countries and by the lack of other alternatives.

4.0 SCENARIOS FOR THE NUCLEAR FUTURES

Three scenarios, or alternate futures, for nuclear power in the U.S. are described within the context of two scenarios for international nuclear power . From these, a number of observations and conclusions regarding the policy implications and R&D requirements for the U.S. are drawn. These U.S. nuclear scenarios are not mutually exclusive, and they can be viewed as representing possible phases in the potential reemergence of nuclear energy as an important element in the country's power spectrum. The three U.S. scenarios are:

- *Gradual abandonment* of the nuclear power option in the U.S..
- *Continued reliance* on the current nuclear generation technologies.
- *Reemergence* of nuclear power as the preferred option for new generating capacity.

These scenarios are discussed in the context of two alternative futures for nuclear power internationally: internationally, nuclear power generation will either grow or wither away. It is, of course, possible that globally, nuclear power may maintain its current share of electrical generation. However, we believe the implications of the international nuclear market on U.S. policy and R&D options are sufficiently bounded by these two limiting cases. Thus, we will consider the implications of U.S. options in the face of two international frameworks:

- *Decline* of nuclear power internationally.
- *Growth* of nuclear power energy generation worldwide.

Essentially all energy projections, including those emphasizing conservation and renewables, predict some growth of nuclear power on a worldwide basis. Rather than discussing in detail all six permutations of the domestic and international scenarios, we will here discuss the U.S. scenarios under the assumption of a growing international nuclear market, then discuss the additional implications a withering international market may have on the U.S. nuclear futures and options.

Each of these scenarios requires certain assumptions and invokes particular implications and challenges. Meeting these challenges will place demands on policy and requirements for R&D. The assumptions and implications are described below. The policy implications and R&D requirements are discussed in section 5.

4.1 Scenario 1: Gradual Abandonment

Under this scenario, there will be no new domestic orders for reactors in the U.S. Most existing reactors will operate through the end of their current licenses. Some (10–15) power reactors may be decommissioned early because of economic pressures caused by deregulation. A few reactors may be operated beyond the end of their current licensed lifetimes.

Assumptions for Scenario 1

Nuclear market: The international market for power reactors will continue to grow, particularly in East Asia, and a new market for small reactors will develop among the developing countries.

Safety: No major nuclear power accidents will occur in the world.

Waste management: Waste management, particularly geological repository development, will make reasonable progress in the U.S., providing an indication to the world nuclear energy community that waste can be managed in the long term.

Cost: In the U.S., deregulation will lead to 10–15 power reactors being decommissioned before the end of their design life. A few reactors could undergo life extension. All other power reactors will continue to perform well and be competitive in cost to other means of power generation. No major change is expected in the world energy cost structure.

Public acceptance: Worldwide public acceptance of nuclear energy will remain in its current state.

Security and proliferation: Security issues (safeguards, security, and proliferation concerns) will continue to increase in the U.S. because of: (1) Expansion of the nuclear option in the developing countries and East Asia; (2) Countries like France aggressively selling nuclear energy technology to those developing countries in order to maintain a viable domestic nuclear energy program; and (3) The U.S. gradually losing influence in nuclear matters, particularly in East Asia.

Light Water Reactor (LWR): The light water reactor (LWR) will continue to serve as the leading technology in the world market. No advanced reactor of any other kind will demonstrate the potential to replace LWR technology within the next 20-plus years.

Domestic Implications of Scenario 1

Since Scenario 1 assumes no new orders will be placed in the U.S., domestic activity will focus on safe operation of existing plants and successful handling of nuclear waste, including completion of the geological repository in what will probably be a deregulated cost structure. The objectives of the resulting U.S. program are therefore as follows:

Safety: The U.S. government's role is to assure that the regulatory process provides additional assurance. Ensuring the safety of aging plants and demonstrating adequate safety for potential life extension will be important goals.

Waste management, particularly the use of a geological repository, is of great importance in the U.S. as well as in the rest of the world: Scientific success is a must. Failure to develop a geological repository in the U.S. would not only be a disaster for U.S. operating plants but also could be a show-stopper in international nuclear deployment. The scientific challenge is enormous, considering the need to maintain public health and safety for not only tens of thousands of years but perhaps as long as many millions of years.

Deregulation will have some impact on the nuclear power industry. Some plants with high operating costs may be forced to shut down before their 40-year design life. Approximately 10–15 plants may be affected.

Security (safeguards, security, and proliferation concerns): The current domestic program is probably adequate. No major new issues are expected.

Infrastructure: With no prospects for a domestic nuclear option, the U.S. nuclear infrastructure will become increasing reliant on an increasingly competitive foreign market. Already, U.S. industry is forced to license technology rather than to manufacture goods and systems. These forces will continue to erode the domestic U.S. nuclear infrastructure. In particular, loss of U.S. nuclear infrastructure and expertise will seriously jeopardize our ability to deal with the long-term nuclear waste and nuclear legacy issues.

International Implications of Scenario 1

International influence: Under Scenario 1, international proliferation is a major concern to the U.S. Without a major effort, the U.S. will lose its influence in nuclear matters. The loss of U.S. technology leadership (with the result that countries such as France will eventually have more advanced technology and will be able to attract international business); and the two-tier policy on proliferation that introduces friction between the U.S. and some other countries. Moreover, the potential for U.S. self-sufficiency in energy supply makes it politically difficult for the U.S. to implement a policy preventing other countries from exercising the nuclear power option.

To support our policy regarding proliferation, we must continue to have an influence in the international nuclear arena. The most effective way of achieving that goal is to maintain U.S. leadership in nuclear technology. We currently have sufficient resources (natural and financial) to provide for secure domestic energy supplies. However, it will be difficult to convince other countries with fewer resources not to pursue the nuclear energy option.

Our nuclear foreign policy is driven more by proliferation concerns than by potential for increased international business. We thus anticipate that other suppliers will gradually take a bigger share of the international market, and our influence on nuclear matters will experience a world-wide decline. We will therefore have less opportunity to influence international proliferation. In the end, our industry will be forced to pull out of international competition. In addition, we will be less able to address international nuclear safety concerns because we will have progressively less information to verify that the receiving countries have been adequately trained by their suppliers. The bottom line for the U.S. is that, although domestic nuclear energy may be phased out, it is essential to maintain a viable nuclear energy activity with adequate R&D elements in order to support U.S. international interests for the following reasons:

- To monitor and affect proliferation matters.
- To influence other nuclear matters worldwide.
- To be the leader in Light Water Reactor technology for the international market in order to help implement proliferation policy and enhance U.S. influence on nuclear matters.

Foreign markets: U.S. technology, on the other hand, is generally more expensive than that of other world suppliers. As a result, U.S. industry is fighting an uphill battle competing in the international market. Although we may believe that the U.S. has the safest LWR design, other world nuclear technology suppliers also meet western safety standards. Thus our claim of a safer design may not add much when we compete in the international market.

4.2 Scenario 2: Continued Reliance on Current Nuclear Technologies

Under this scenario, nuclear power will continue to be relied on and will likely maintain an approximate 20% share of the country's electrical generating capacity. Although some (10–15) power reactors may be decommissioned early because of economic pressures caused by deregulation, and a few reactors may be operated beyond the end of their current licensed lifetimes, new evolutionary reactor design and construction will proceed to take up the additional demands arising from decommissioning and growth in electricity demand.

Assumptions for Scenario 2

With regard to the nuclear energy situation in U.S., the following assumptions are made:

Nuclear power purchases: The U.S. would like (or is compelled) to strive to maintain a 20% share of its electricity generated by nuclear power. This may be driven by environmental concerns about fossil fuel. New orders would be placed during the next 10–15 years to replace retired reactors or reactors retired earlier due to lack of cost competitiveness.

Price deregulation. Nuclear power must be competitive in cost in order to stimulate the utility industry's interest in placing orders in a continuing environment of deregulation.

Public understanding and acceptance of nuclear energy. Enhanced public acceptance is essential for significant new domestic orders.

New nuclear power systems. New systems that integrate the entire nuclear fuel cycle from fuel to reactor systems to waste management, with attention to cost and proliferation concerns, are a must if the second generation of nuclear power is to begin.

Domestic Implications of Scenario 2

In addition to the implications under Scenario 1, a number of some additional implications arise, and some of the Scenario 1 implications must be expanded.

Safety, including related quality assurance and regulatory practice, will continue to be a dominant concern. However, economic pressures will force a shift in safety, quality assurance, and regulatory philosophies towards achieving demonstrable safety improvements in real terms. This shift in philosophy will, by necessity, lead to evolutionary improvements in reactor design, and may result in significantly new reactor concepts.

Waste management must be demonstrated as an achievable in practice. Integration of waste management within the context of the overall fuel cycle will be an important element of success.

Infrastructure: Continuing to rely on the U.S. nuclear option at roughly its current levels will help maintain our infrastructure to cover future needs. However, the lack of a clear mandate for significant technical innovation will limit the growth and capabilities of that infrastructure. At the current level of nuclear generation, and an anticipated growth rate in U.S. electrical demand of 1.5%, this scenario translates into only one 1500-MWe unit per year. This rate may be too low to maintain industrial capability unless significant export sales help support the industrial infrastructure necessary.

International Implications of Scenario 2

Safeguards and security: Although current safeguards and security practices are likely sufficient for domestic purposes, the intrinsic validation of the nuclear power option under this scenario will likely lead to development of improved safeguards and security measures as a model for the rest of the world.

International influence: Our ability to influence foreign nuclear decisions relies on the U.S. position as a reliable supplier of world-class technology. Continuation of the domestic nuclear option would enhance the U.S. ability to maintain its influence in nuclear matters worldwide.

Foreign markets: Maintenance of the U.S. nuclear option will serve to maintain or increase the presence of the U.S. and its nuclear industries in the world nuclear markets.

4.3 Scenario 3: Reemergence of Nuclear Power as the Preferred Option for New Power

In this scenario, nuclear power's share of the U.S. electrical generation capacity would increase, possibly due to increasing environmental concerns associated with fossil fuels and increasing costs and diminishing supplies of those fuels.

Assumptions for Scenario 3

It is difficult to foresee the distant future. Many elements, such as fossil fuel availability, changes in energy demand, international power shifts, environmental concerns, or new technology breakthroughs, can affect decisions on nuclear energy. Clearly, the further out we project, the higher the uncertainty. Thus benchmarking our projections against social, economic, and political realities from time to time is necessary. In Scenario 3, we assume that:

Technical breakthroughs in energy technology for base-load electricity generation (such as renewables or fusion) do not occur during the next 30–50 years.

Environmental concerns related to fossil fuel consumption, including global warming, acid rain, and others are confirmed to be harmful.

Economics of fossil fuel consumption becomes increasingly unsatisfactory due to increased fuel costs and increased costs of pollution prevention measures.

Domestic Implications of Scenario 3

Reactor technology development must proceed along revolutionary rather than evolutionary lines, with even greater emphasis on inherent safety and overall systems integration.

Fuel cycle development, carefully integrated with reactor systems and supporting infrastructures and focused on resource conservation and waste minimization, will become increasingly important.

Regulatory, siting, and operational philosophies need to shift towards improving overall system efficiencies, emphasizing standardized design, commonality of operations and procedures, and better accounting for social and political realities.

International Implications of Scenario 3

Foreign markets: Reemergence of the U.S. as the leader in nuclear technology and infrastructure can reestablish our role in the international nuclear markets. The international community embraced U.S. reactor and safety designs, and most foreign manufacturers reactor designs are based on U.S. designs. New generations of U.S. designs, featuring enhanced safety and proliferation resistance, will significantly impact the international markets.

International influence: Our ability to back up U.S. goals and interests with demonstrable technologies and systems will advance our ability to influence international nuclear policy and decisions.

5.0 POLICY AND R&D REQUIREMENTS

The demands of each of the three scenarios will require research and development and modifications to policy. Even under Scenario 1, R&D activities are required to meet domestic safety, environmental, and waste management requirements, as well as to maintain sufficient credibility to meet international policy objectives.

Just as the scenarios themselves are not mutually exclusive, the needs of each scenario relies on R&D and policy from the preceding and contributes to the next-higher scenario.

5.1 Policy and R&D Requirements for Scenario 1

As already pointed out, two great challenges face the U.S. if it essentially abandons the nuclear energy option: (1) maintaining sufficient influence in international nuclear energy policy and politics, and (2) ameliorating the impact of nuclear waste and the nuclear legacy.

International Cooperation and Dialog

International collaboration is an important part of the U.S. nuclear research agenda in areas ranging from collaboration in technical projects to support of State Department policy initiatives. Examples include:

- Joint international nuclear technology development projects aimed at improving the long-term safety and performance of nuclear power plants.
- Joint international cooperation on development and application of nonproliferation technologies.
- Participation in research and development programs coordinated or sponsored by international organizations.
- International safety information exchange.
- Agreements with foreign countries or regional organizations furthering U.S. nonproliferation and safety objectives.
- Increased direct dialogue and cooperation, most notably with China and other East Asian countries.
- Establishing a strong U.S. role in regional nuclear energy cooperation frameworks, particularly in East Asia.

The most unpredictable country in terms of nuclear development is China. China often has the same desires as the U.S. but disagrees with our methods. A discussion with China on nuclear matters, dealing as equals, could be much more effective than current approaches in dealing with some of our proliferation concerns. Opening a scientific channel for discussion with China is a good investment for both short-term and long-term goals. Since China is aggressively developing nuclear power, it will be relatively easy to establish dialogue on nuclear energy, particularly about U.S. technology and safety experience.

Only when we have a major role to play in the international arena can we have influence on nuclear matters. Our influence in Europe on nuclear matters is not as great as desired because of the strong role that the French play in that region. We are not even a member of EURATOM, a union of European countries on nuclear matters. Our effort to seek nuclear transparency in that region has had to rely on our allies and on the International Atomic Energy Agency (IAEA). It is obvious that Asian Pacific countries are going to organize nuclear cooperation with or without U.S. participation. We must avoid repeating our European experience. Thus, we must participate in arrangements on East Asian regional cooperation on nuclear energy as a member and hopefully a major player.

Safety

Maintaining safe operation of the 109 operating commercial nuclear power reactors is the primary responsibility of the nuclear power utilities and industry. The U.S. government's role is to assure that the regulatory process provides additional assurance. Research should focus on operational safety enhancements, such as digital instrumentation and control upgrades, control system enhancement, fire prevention and control, operator training and human engineering integration, etc. Most of these R&D activities will be carried out by industry; only those requirements involving advanced technology with significant potential effect on safety and commonality to all plants should be sponsored by the Federal government. Digital I&C is in that category.

Waste Management

Waste management, particularly the use of a geological repository, is of great importance in the U.S. as well as in the rest of the world: Scientific success is a must. Failure to develop a geological repository in the U.S. would not only be a disaster for U.S. operating plants but also could be a show-stopper in international nuclear deployment. The scientific challenge is enormous, considering the need to maintain public health and safety for not only tens of thousands of years but perhaps as long as many millions of years. A strong R&D program must therefore be continued, emphasizing a combination of engineering barriers with a natural barrier system. In a worst-case situation in which the repository development is unsuccessful, we may have to use dry storage either on-site or at a centralized location to temporarily store the spent fuel for up to 50 years or more. The technology and licensing process are mature for dry storage and thus this area requires little R&D.

Spent Fuel Minimization and Advanced Fuels Development

A major priority is to develop and test very-high-burnup nuclear fuels that will significantly reduce the amount and cost of commercial spent fuel disposition by the government. In addition, some work should be done on the development of more proliferation-resistant fuels that might be used in either current LWR systems or potentially in small, low-cost reactors for export.

Small Reactor System Development

Maintain involvement in the development of a small reactor system (50 MWe~150 MWe) that can be used for electricity generation and / or desalination of water. This system must take the entire nuclear fuel cycle into consideration, using risk-based decision analysis to achieve the proper balance in fuel supply, waste generation handling and disposal, proliferation resistance, safe operation, and cost effectiveness. The system should have the following features:

- *No on-site refueling* in order to reduce proliferation concerns with operation life targeted for 10–15 years. The entire reactor will be shipped back to the factory for refueling and a new reactor installed. During the process, electricity and water desalination could be provided from reactors located on a transport barge.
- *High safety margin.*
- *Automated* operation and easy handling.
- *Minimized waste stream*, acceptable to geological repository.
- *High cost-effectiveness.*

There is a demand for such a system; and the system would address U.S. concerns on proliferation, safety, and U.S. leadership in technology and would enhance U.S. influence on nuclear matters. Without U.S. involvement, the development of such a system may be carried out by some other country for which the "no on-site refueling" criterion may not be honored. This small-reactor exercise, which integrates the entire fuel cycle including safety and cost into system development, is of long-term importance. Work on a small-reactor-system can be partially justified by the fact that it provides good practical experience if we have a need in the future for large-reactor-system fuel cycle integration, as discussed in Scenario 2. The technology required for certain parts of the system already exists. The most important task is the integration of all elements to achieve the most efficient and balanced design. Automation may be an important challenge. Japan, Korea, France, and Canada are working on automated instrumentation and controls in their nuclear power programs. This small-reactor initiative could also bring the U.S. back into the competition in the area of automated I&C applications, which can also benefit other industries.

Integration of the Nuclear Fuel Cycle

Research and analysis to develop and nuclear systems options from a total fuel cycle standpoint including cost, resource conservation, waste minimization and proliferation resistance. Concern about proliferation is the main reason for the U.S. policy on reprocessing. Since the U.S. is no longer the sole source of nuclear power reactors in the world, it will be very hard to further this proliferation policy. We may have to change our practice from trade control, export control and punishment to participation and cooperation. We must demonstrate that we are the technology leader and know the rest of the world's energy needs. We will use our technology to help, while at the same time addressing our other concerns.

Our policy on reprocessing is derived from the Nonproliferation Alternative Systems Assessment Program (NASAP-1980 - Carter Administration) in 1980. At the same time the international community conducted a similar study, International Nuclear Fuel Cycle Evaluation (INFCE), and reached a totally different conclusion. Both studies reached very similar technical conclusions but led to totally opposite policy results. Today we have a much greater operational experience in reprocessing through experience in the weapons program. France and Russia also have operational experience through both weapons and commercial nuclear programs. It is time to reassess our reasoning in reaching our position on reprocessing, taking into account the total system: the waste generated by reprocessing, the environmental consequences, the cost and the need for infrastructure, and proliferation concerns. A systems study covering all of these elements may still demonstrate that reprocessing is not the best choice. However, it will be much easier to convince other countries not to reprocess on that basis. Most countries do not have reprocessing experience, so they do not have adequate information with which to perform their own assessments.

Global Fuel Cycle Safety, Security, and Accountability

Research into materials, processes and technologies contributing to the enhancement of the safeguards, security, and accountability regimes of both current and future fuel cycles is needed to meet national security objectives and to help resolve public concerns.

5.2 Policy and R&D Requirements for Scenario 2

For Scenario 2 to become reality, nuclear power must be accepted as a safe, clean, and affordable source of power. Improvements in the economics and perceived safety of nuclear energy will require significant changes in nuclear energy policy, particularly with respect to safety, safety philosophy, and public understanding. Safety improvements must be accomplished along several fronts: real improvements in safety and plant operations; improvements in safety philosophy, regulations, and standards; and improvements in the public's understanding of nuclear safety and their perception of nuclear energy in general. In addition, increased attention to better integration of the fuel cycle, including waste minimization and proliferation-resistant fuel cycles, will become increasingly important.

Safety Regulations and Standards Reform

During the rapid growth of nuclear power in the late 1960s, cost was not a primary concern of either the government or industry. Waste generation, handling, and disposal were viewed as issues to be dealt with in the future. Nuclear power was considered a privilege of the big nuclear weapon states. The U.S. may have had enough influence to dictate to the world community concerning proliferation concerns. Public support of nuclear power was taken for granted, because of the general acceptance of the idea of peaceful use of the atom. Knowledge of the differences between boiler and nuclear reactor design, construction, operation, and in particular accident management was not mature. Since cost was not a major concern, the U.S. established many safety regulations or standards that may, at times, have contributed little to safety, and sometimes even had an adverse effect, but increased cost substantially.

As a result, a 1000-MWe nuclear power plant has 40,000 pumps in comparison with the 4,000 pumps in a fossil power plant with the same 1000-MWe capacity. In reality, the essential difference between nuclear power plants and fossil power plants is that a boiler is replaced by a nuclear reactor. Many protection systems were added, often with two to three levels of redundancy. Of course, we now know that more redundancy does not always improve safety, because redundancy may be lost due to common failure modes, such as earthquakes.

The 10-fold increase in components introduced complexity in design, construction, operation, maintenance and repair, and most significantly accident management. The control room became filled with instruments to show component status, which led to an almost-impossible task for an operator attempting to manage an accident. After the Three Mile Island (TMI) accident and following more than 15 years research and development, we now realize that our control room designs need to be modified. The U.S. has a large-scale control room upgrade task under way. Although control room upgrades may be necessary, the real issue is whether nuclear plants require 10 times more components (i.e., whether those components really enhance safety or perhaps have adverse effects). Although there is little to be done for the existing plants, for future plants (even those with standard LWR technology), we must strike a proper balance between various parameters in design.

There are no doubt many other so-called safety requirements that are questionable in real value, but are certainly costly. Thus Scenario 2 requires that we establish a program to review, identify, and conduct R&D to assess safety standards and regulations of this nature and propose changes. Our extensive experience with the many plants built and operated should allow a useful look at nuclear safety from a systems standpoint. The concentration should be on LWR technology since it will be the approach of choice for the foreseeable future. A 20–50% cost reduction might be achieved without jeopardizing safety.

Quality Assurance (QA) Reform

The American Society of Mechanical Engineers (ASME), Section III Code was developed during the last 20 years to replace the Section 8 Code for nuclear construction. Section III Code has reduced safety margins built into the code but increased inspection and assurance requirements to reduce uncertainty. In implementing this philosophy, ASME introduced quality assurance (QA) requirements to assure that quality is confirmed and uncertainty is indeed bounded. Unfortunately, the QA program was heavily influenced by legal thinking and established a very systematic and burdensome paper trail of documentation control to satisfy litigation concerns. In reality, the actual quality enhancement is not in proportion to the burden it creates. Certain portions of the QA program are beneficial and have safety importance. Other portions need to be reviewed for their significance. We may have to separate the quality assurance from legal protection considerations so that our future QA program can enhance safety at a justifiable cost. A rough estimate is that current QA programs add 10–15% in nuclear plant design and construction cost. The real effect on quality is not well understood.

Regulatory Philosophy Reform

The first generation of nuclear power programs taught us an important lesson. The assignment of responsibility and accountability was not very clearly defined between government and industry. For the future generation of nuclear power programs, we must clearly define responsibility and accountability. The utility, or the owner / operator of a nuclear plant, should be responsible for safety and public protection, and also be accountable for liability. The regulator (i.e., the NRC) should be an oversight organization to assure that industry is fulfilling its responsibilities. Therefore, safety regulations should not be prescribed in too much detail. Instead, industry must be given a certain amount of room to make judgmental decisions that balance liability and cost. The new, one-step licensing process is headed in the right direction. More needs to be done to define the regulator's role and industry's responsibility.

Improvement of Public Understanding and Perception of Nuclear Energy

During the past 30 years, the general public had been misinformed on nuclear energy. It had been told that nuclear power was so safe (with all the many safety protection systems in place) and that the nuclear power safety performance record was so good, that there was no need for concern. The public's lack of knowledge is such that it panics when any incident occurs in a nuclear power plant, whether it is a nuclear or a non-nuclear incident, or whether it is an incident within design limits or a real accident requiring great concern. When many small incidents accumulate, the public wonders if nuclear plants are as safe as they have been assured (after all, things seem to go wrong even though there are so many safety systems). The public must be provided with a correct picture in which nuclear power is described as any other high-technology product, (e.g., that incidents within design limits are expected and that the plant is designed for them). An aggressive public information (or re-education) program is needed involving a very clear description of accident types and risk consequence. This program should be part of the school program, perhaps starting at the junior high level. A period of 20 years passed while public perceptions on nuclear energy changed from totally supportive to negative. It will take at least 20 years to reverse the process. Without public support, nuclear power in this country has little future.

Safety

Along with changes in safety philosophy, regulations, and standards, new methods of safety design and analysis must be developed to support those reforms.

Integration of the Nuclear Fuel Cycle in Large Systems (1000 MWe+)

We should not fund any reactor technology development (even on the Light Water Reactor system) until we have taken the totally integrated nuclear fuel cycle into consideration (including cost, proliferation concern, and waste management). In Scenario 1, we recommended the development of a small reactor system to start the process of integrating the nuclear fuel cycle. Starting with a small reactor system instead of a large reactor system was due to the reality that large reactor systems will not be ordered soon, because we have 109 reactors in operation, and to the fact that a small reactor system is urgently needed by developing countries where the U.S. may have great concerns about proliferation. If it is believed that more orders for nuclear power reactors will be placed in the U.S. during the next 10–15 years, then we must start to assess which reactor system can produce less waste and waste acceptable to a repository, has the least proliferation potential if exported to foreign countries, has high safety margins, and is very cost-effective. If Scenario 1 activities are pursued and progress successfully, the development of a large-size nuclear power reactor system should be started to prepare for the future needs. If, in addition, regulatory reforms, cost reductions, and safety improvements are pursued successfully, and a totally integrated nuclear fuel cycle is identified, then in-depth R&D for further development and deployment of that system must be supported.

5.3 Policy and R&D Requirements for Scenario 3

Under these assumptions, we must think seriously as to which fission reactor technology should be developed for future generations (i.e., for 30 years from now and beyond). Following our experience gained during Scenarios 1 and 2 on integrating the nuclear fuel cycle, it is necessary to identify and further develop new fission reactor technologies. Can we predict which fission technology will be the choice for the future? Certainly not. Even for today, LWR technology may not be optimal, but it is the best current choice considering present social, economic, and political realities. For us to introduce a new technology to replace one commonly used, we must consider the total system. That total system includes not only reactor technology, fuel cycle considerations, and cost but also infrastructure needs, public understanding, regulatory framework, etc. It is clear that the U.S. cannot afford to introduce many new technologies at the same time. Research and development should thus be focused on a few technologies. A choice will then have to be made of the one technology, for further intensive R&D, and the required development of the entire system carried out. Only when the entire system is in operation and has been demonstrated will society be ready to accept it. This is the lesson learned from the first generation of nuclear power. It should be remembered in order to avoid the same mistake during the second generation.

6.0 IMPLICATIONS OF ALTERNATIVE INTERNATIONAL NUCLEAR POWER FUTURES

The state of nuclear power generation internationally has and will continue to have significant impact on U.S. nuclear policy, the U.S. nuclear marketplace, and on our research and development agenda. While the U.S. has some influence in international nuclear issues, history has demonstrated that the U.S. can only influence, not directly change, the international nuclear marketplace. It is also clear that historically the U.S. ability to influence the international nuclear community has been tied to the relative technological strength of U.S. nuclear technologies, expertise, and supply.

If the current growth of nuclear power internationally were to stop, and international nuclear power were to decline, what would be the implications to the U.S.?

First, a decline in nuclear power would reduce the ultimate generation and accumulation of spent fuel and potential separation and accumulation of plutonium through reprocessing. This would contribute to a reduction of proliferation risk worldwide, particularly if the decline progressed slowly. In the event of a "catastrophic" decline in nuclear power (for example, in the event of a major reactor accident), the significant quantities of commercially separated plutonium (most notably owned by the French and Japanese and now slated for consumption as MOX) would require disposition similar to today's stocks of excess weapons plutonium. There would be an even greater need for new forms of long-term international safeguards and security to protect this material.

Second, U.S. influence in international nuclear issues is strongly dependent on the relative strength of U.S. technology and U.S. nuclear position relative to the rest of the world. A decline in worldwide nuclear power would, by default, improve the influence of the U.S.

Third, a worldwide decline of nuclear power would place the same stresses on, and endanger the maintenance of, the world's nuclear infrastructure that abandonment of nuclear power would place on U.S. infrastructures. Just as in the U.S., the worldwide nuclear legacy (waste, spent fuel, plutonium, and decommissioning) will not disappear, and there will be a critical need for expertise and infrastructures to deal with these legacy issues well beyond the decline of nuclear power generation.

Fourthly, even without nuclear power, the world's consumption of primary energy is certain to increase, with the most rapid increases occurring in the developing countries and in East Asia. Without nuclear power, much of this increase must be taken up by coal and other fossil fuels. This will increase global release of carbon dioxide and other environmentally sensitive emissions, and increase the demand and competition for oil and gas.

6.1 Policy Implications of a Declining International Nuclear Role

Nonproliferation would continue as a major policy issue for the U.S. and the international community. With no clear use for remaining stockpiles of commercially separated spent fuel, international safeguards and international spent fuel and plutonium disposition will gain importance.

U.S. influence would potentially improve under an international nuclear decline, but simultaneously so pressure would grow for the U.S. to accept increased responsibility for assistance in dealing with the remaining legacy.

International nuclear safety could be threatened by dwindling nuclear expertise and infrastructures. The U.S. would become increasingly relied on to support safety programs for the remaining nuclear programs.

6.2 R&D Implications of a Declining International Nuclear Role

Without a need for new forms of nuclear generating capacity, R&D in related technologies would decrease in importance. However, with the changing nature of nonproliferation concerns, the need to invest in new safeguards technologies for potentially long-term monitoring of spent fuel and commercially separated plutonium would take on new importance. Similarly, many foreign nations may have to modify plans for spent fuel disposal, and new technologies for spent fuel and fissile materials disposition would be needed to meet the differing needs of diverse countries and programs. Renewed interest in internationally monitored disposition regimes may take on new importance.